

Soil and Water Conservation Engineering

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I. INTRODUCTION

Agricultural Engineering is a profession that looks not only in the productivity of a farm but more importantly its long term sustainability. A good agricultural engineer takes into consideration factors that need to be addressed to achieve the optimum production without neglecting and putting in peril the needs of the future. And only by understanding these factors could someone harness its full potential and at the same time put the necessary intervention for its protection. Two of the most important resources in agriculture are the soil for which the plants grow and draw nutrient and the water for which the plants and practically all life forms are mostly made of.

Soil and water conservation is a very broad subject matter. It touches many topics in hydraulics, irrigation and drainage because of the natural interaction of soil and water. The discussion will cover the following topics in the manner presented.

A. Facts and Figures

B. Hydrology

1. Hydrologic Cycle
2. Precipitation and Data Analysis
 - a. Rainfall Occurrence
 - b. Types of Rainfall
 - c. Spatial Distribution
 - d. Frequency Analysis

C. Runoff

1. Runoff Components
2. Important Properties of Runoff
3. Factors Affecting Runoff
4. Hydrograph Analysis
 - a. Baseflow Separation
 - b. Direct Runoff Hydrograph Development
5. Streamflow Measurement
 - a. Water Stage Measurement
 - b. Discharge Measurement
6. Estimating Volume of Runoff
 - a. Rational Equation
 - b. Cook's Method
 - c. Curve Number
 - d. Other Methods

D. Erosion and Sediment Transport

1. Types of Erosion

2. Factors Affecting Erosion
3. (Modified) Universal Soil Loss Equation

E. Erosion Control Measures

1. Biological/Vegetative
2. Engineering
 - a. Terracing
 - b. Conservation Structures
3. Vengineering

F. Open Channel Flow

1. Types of Flow
2. Flow Measuring Devices/Structures

G. Definition of Terms

II. OBJECTIVES

The general objective of this subject matter is to instill into the mind of an agricultural engineer that other than farm productivity, part of his/her responsibility is to conserve the very resource that is being tapped, soil and water. This can only be achieved by properly understanding its properties, the processes involved, the ways to maximize its potential and the proper measures to control or prevent the adverse effects it may cause.

Specifically this aims to let the reviewer:

1. appreciate the topic by knowing some facts and figures;
2. understand the basic principle of hydrologic cycle and its processes;
3. understand precipitation and runoff considering its capacity to be beneficial and destructive at the same time;
4. learn to compute and predict precipitation, runoff and soil erosion as a prerequisite to harnessing its potential and/or averting its damaging effects;
5. learn the ways to control soil erosion;
6. understand some basic principles and computations in open channel hydraulics;
7. broaden his/her knowledge by knowing the some terms usually used in the soil and water conservation; and
8. enhance his/her problem solving capability through sample computations and problems.

III. SOIL AND WATER CONSERVATION TOPICS

A. Facts and Figures

Inventory of water at the Earth's surface and its Residence Time

Reservoir	Volume (km³ x 10,000,000)	Percent of Total (%)	Approximate Residence Time (years)
Oceans	1370	97.25	
Ice Caps and Glaciers	29	2.05	40
Groundwater	9.5	0.68	200 (shallow) 10,000 (deep)
Lakes	0.125	0.01	100
Soil Moisture	0.065	0.005	0.2
Atmosphere	0.013	0.001	

Streams and Rivers	0.0017	0.0001	0.04
Biosphere	0.0006	0.00004	

B. Hydrology

Important Processes in the Hydrologic Cycle

- | | |
|---------------------------------------|---------------------|
| 1. Evaporation | 6. Percolation |
| 2. Transpiration (Evapotranspiration) | 7. Surface Runoff |
| 3. Condensation | 8. Interflow |
| 4. Precipitation | 9. Groundwater flow |
| 5. Infiltration | |

Importance of Some Hydrologic Data

- Precipitation -needed in estimating runoff, planning erosion control measures, planning for irrigation and drainage, and water conservation in low rainfall regions
- Runoff - needed in designing structures and channels that will handle natural flows of water
- Infiltration, Evaporation and transpiration -required in planning irrigation and drainage systems, moisture conservation practices, etc.

Types of Precipitation

1. **Convective Precipitation** - caused by the rising of warmer, lighter air in colder, denser surroundings.
2. **Orographic Precipitation** - results from mechanical lifting of the air mass over mountain barriers.
3. **Cyclonic Precipitation** - associated with the movement of air masses from high-pressure to low-pressure regions.

Non-frontal - air is lifted through horizontal convergence of the inflow into a low pressure area

Frontal - lifting of warm air over cold air at the contact zone between air masses having different characteristics

Spatial Distribution

1. **Arithmetic mean** - this involves the averaging arithmetically all the rainfall depths measured by the rain gages within the area.

$$P = \frac{\sum_{i=1}^n P_i}{n}$$

2. **Thiessen polygon** - location of the rain gauges are plotted on the map of the area and stations are connected by straight lines. Perpendicular bisectors are constructed on each of the connecting lines thereby forming polygons enclosing each rain gage. The average rainfall over the area is then estimated as the area weighted average for all polygons. Thus, the average precipitation over a watershed is computed using the equation:

$$P = \frac{\sum P_i A_i}{A_{Total}}$$

3. **Isohyetal** - station locations and amounts of rainfall are plotted on a suitable map, and contours of equal precipitation (isohyets) are then drawn. The equation

used is similar to that of Thiessen method except that the area, A_i , is the area under one isohyet, P_i .

4. **Grid-Point Method** – computer aided method wherein it averages estimated precipitation at all points of a superimposed grid.
5. **Inverse Distance Ratio Method** – for rolling areas and non-uniform distribution of gages, distance factor fixed by location of gages is used for analysis using this method. It operates under the principle that the value of points close together in space are more likely to be similar than with points farther apart.

Frequency analysis

Conservation structures constructed, i.e. to convey runoff, should be designed to handle the maximum expected events. The maximum expected runoff, for example, can be calculated if the maximum expected rainfall is known. The maximum expected rainfall depends upon the frequency that is taken into consideration. This frequency or recurrence interval is defined as the number of years during which one storm of a given duration and intensity is expected to occur.

Hydrologic processes are said to fall under stochastic, probabilistic or deterministic processes. Nevertheless, literature says that most hydrologic processes are stochastic in nature (more or less).

Deterministic Process – one in which a definite law of certainty exists

Probabilistic Process – governed by chance; time series INDEPENDENT

Stochastic Process – governed by chance; time dependent

For simplicity in dealing with hydrologic data, probabilistic process is assumed.

Frequency Distribution / Probability Density Curve

1. Normal Distribution – data is more or less normally distributed
2. Log-Normal Distribution – used when there is skewness in the data distribution
3. Pearson Type III Distribution -- considers further the skewness of the logarithmically transformed hydrologic data; preferred for flood flow frequency; log-normal distribution is a special case of this method
4. Gamma Density Function – so far gives the best fit for most stations for 1-week, 2-week, 3-week and monthly rainfall totals of the country

C. Runoff

Runoff Components

1. **Surface Runoff** -- that which travels over the ground surface and through the channels to reach the basin outlet
2. **Interflow** – that which infiltrates into the soil surface and moves laterally through the upper soil horizons towards streams as perched groundwater above major groundwater level
3. **Groundwater Runoff** – groundwater discharge into a stream due to deep percolation of the infiltrated water into groundwater aquifers

Other terms:

- a. **Overland flow** – that part of surface runoff that flows over the surface towards the stream channel

- b. **Direct runoff** – surface runoff plus interflow
- c. **Subsurface runoff** – same as interflow
- d. **Baseflow** – same as groundwater runoff

Important Properties of Runoff

- 1. **Peak Flow (q_p)** – used to determine the magnitude of floods and a valuable consideration in the design of structures
- 2. **Time to Peak (t_p)** – used for flood forecasting and water quality studies; watershed response time
- 3. **Runoff Volume (V)** – total water yield from a storm for a given watershed
- 4. **Recession Time (t_r)** – time for surface and interflow to recede; duration of flooding
- 5. **Base time (t_b)** – total of time to peak and recession time; $(t_b) = (t_p) + (t_r)$
- 6. **Base flow** – low flow, dependable flow, groundwater discharge

Factors affecting runoff

- Climatic factors
 - Precipitation
 - Form
 - Intensity
 - Duration
 - Time Distribution
 - Areal Distribution
 - Direction of storm movement in relation to the orientation of the watershed
 - Frequency of occurrence
 - Antecedent precipitation
 - Vegetation Interception of Rainfall
 - Evapotranspiration
- Physiographic factors
 - Watershed characteristics
 - Size
 - Shape
 - Slope
 - Orientation
 - Elevation
 - Stream Density
 - Land use and cover
 - Infiltration characteristics
 - Geologic Conditions (e.g. permeability, aquifer transmissivity and storage coefficient)
 - Topographic conditions (e.g. depression storage, lakes, swamps)
 - Artificial Drainage
 - Man-made modification (e.g. dams, terraces, etc.)
 - Channel characteristics
 - Slope
 - Length
 - Cross-section slope
 - Roughness of channel bed

- Tributaries
- Storage Capacity (e.g. backwater effects)

Hydrograph Analysis

A **hydrograph** is a graphical representation of the instantaneous runoff rate against time. The area under the hydrograph gives the runoff volume.

Direct Runoff Hydrograph Development

Basic Hydrograph

- assumes that all hydrographs from all small watersheds (in the US) have similar forms
- it is plotted over 100 arbitrary units of flow and 100 arbitrary units of time

Triangular Hydrograph

- approximation of the basic hydrograph
- developed mainly to simplify flood routing procedures in US

Unit Hydrograph

- a hydrograph with a unit volume (e.g. 1cm) of direct runoff for a given storm duration
- represent the response of the basin on a given storm duration and characteristics
- enables one to synthesize hydrographs for complex storms by superimposing the hydrographs resulting from the individual components of the storm

Synthetic Hydrograph

- prepared using data from a number of watershed to develop dimensionless unit hydrographs which are applicable to ungaged watersheds
- a dimensionless hydrograph is made from natural or unit hydrographs in which the time to peak (t_p) and the peak runoff rate (q_p) are considered and t/t_p is plotted against q/q_p

Streamflow Measurement

Water Stage Measurement

1. **Staff Gage**
2. **Crest Stage Gage** -- provide record of the highest stage observed at a stream
3. **Bubbler Gage** -- record the pressure required to maintain a small flow of gas from an orifice submerged in the stream
4. **Float-type Water-Stage Recorder** -- motion of a float is recorded on a graph

Discharge Measurement

1. **Float method** -- measures the velocity of a floating object preferably in a straight section of a stream
2. **Current Meters**
 - a) Price (Cup-type) Meter
 - b) Propeller-type Meter

utilizes the equation or relation:

$$V = a + bN$$

Where: V - water velocity

a - starting velocity or velocity required to overcome mechanical friction

b - constant of proportionality

N - revolution per seconds of the meter cups / propeller

Note: To get the average velocity of a stream, measurement of velocity must be taken at 1/5th and 4/5th of vertical depth below the surface for deep streams, or at 3/5th of the vertical depth for relatively shallow streams.

3. **Use of Manning's Equation** and similar empirical formula

4. **Weirs and Flumes**

5. **Stage-discharge Relation (Rating Curve)**

Estimating Volume of Runoff

Rational Method

$$Q = \frac{C * I * A}{360} \quad (\text{Metric})$$

$$Q = C * I * A \quad (\text{English})$$

Where: Q = peak runoff rate (cms or cfs)
 I = rainfall intensity (mm/h or in/h) for a duration equal to the time of concentration and for the given return period
 A = catchment area (ha or acres)
 C = runoff coefficient = ratio of the peak runoff rate to the rainfall intensity

Time of concentration,

$$t_c = 0.02 L^{0.77} S^{-0.385} \quad (\text{Metric})$$

$$= 0.0078 L^{0.77} S^{-0.385} \quad (\text{English})$$

L = maximum length of flow (m or ft)

S = watershed gradient (ft/ft or m/m) or the difference in elevation between the outlet and the most remote point of the watershed

Cook's Method

$$q = P R F$$

Where: q = peak runoff rate for a specified geographic location and a given recurrence interval

P = peak runoff rate on a 10-year recurrence

R = geographic rainfall factor

F = recurrence interval factor

Curve Number Method

$$Q = \frac{(I - 0.2S)^2}{(I + 0.8S)}$$

Where: Q = direct surface runoff depth (mm)

I = storm rainfall (mm)

S = maximum potential difference between rainfall and runoff starting at the time the storm began

$$S = \frac{25400}{CN} - 254$$

CN = curve number ranging from 0 to 100; function of land use, antecedent moisture, soil type, hydrologic condition

D. Erosion and Sediment Transport***Effects of soil erosion:***

- Loss of soil fertility
- Raising the beds of streams and rivers, thus reducing their capacity
- Silting of reservoirs, thus reducing their capacity and useful life
- Damage to agricultural lands due to soil deposition.

Types of soil erosion:

- Water erosion
 - *Splash / Raindrop Erosion* – primarily caused by raindrop
 - *Sheet erosion*- a thin film of soil layer detached and transported by water flowing on the land surface.
 - *Interrill erosion* – combination and splash and sheet erosion
 - *Rill erosion*- finger-like rills appear on the soil surface.
 - *Gully erosion*- advanced stage of rill erosion. Rills when neglected develop in size and become gullies.
 - *Stream bank erosion* – erosion of stream banks by flowing water.
 - *Coastal erosion*- erosion caused by wave action on the seashore.
- Wind erosion – caused by high velocity winds moving over barren land surfaces.
- Slip erosion – land slides and slips due to saturation of steep hills and slopes.

Factors affecting soil erosion

- Climatic factors – precipitation, wind, temperature, humidity and solar radiation
- Soil physical properties influence the extent to which soil can be dispersed and transported.
- Soil structure, texture, organic matter content, moisture content, and bulk density.

Vegetation acts in the following ways:

- Interception of falling rain by the foliage helps in absorbing the energy of raindrops.
- Transpiration, thus decreasing soil moisture and increasing storage capacity of the soil
- Binding effect of root system helps retard erosion
- Decayed roots provides cavities and pores which promotes infiltration
- Increase surface friction reduces runoff velocity

- Increased biological activity in the soil enhancing its good tilth

Topography

- Degree of slope
- Shape and length of slope
- Size and shape of the watershed

Universal Soil Loss Equation

$$A = R * K * LS * C * P$$

Where: A = Average soil loss for the given period

R = Rainfall erosivity factor

K = Soil erodibility factor

C = Cropping management factor

L = length of slope factor

S = slope factor

P = conservation practice factor

E. Erosion Control Measures**Vegetative Measure**

1. **Reforestation** - replanting of forest trees species in the watershed area
2. **Agroforestry** - a practical adaptation of reforestation whereby the species planted have economic value, such as mango, pili and so on.
3. **Strip cropping** - is the practice of growing different crops in alternate strips across the slope to serve as barriers for soil erosion.
4. **Mulching** - the process of covering the land surface with plant residues, plastic or other materials appropriate to arrest loss of moisture through evaporation
5. **Contour cultivation** - consists of carrying out agricultural operations very nearly on the contour. It reduces the velocity of overland flow and retards soil erosion
6. **Cropping systems** - modification of cropping system such as crop rotation and mixed cropping

Engineering Measure

1. **Terracing** - construction of earth embankment or ridge and channel across the slope at an acceptable grade to control the flow of runoff as well as soil particles.
2. **Grassed Waterways** - establishment of natural waterways or construction of canals and planting it with grasses to make it stable and arrest soil erosion
3. **Check dams or weirs** - constructed along the channel or waterway to control the velocity of flowing water and encourage deposition of sediments carried by water
4. **Farm Ponds / Water Impounding Dams** - temporary detainment of water in farm pond and dams to mitigate the erosive capacity of water
5. **Diversion Canal** - a channel constructed around the slope and given a slight gradient to cause water to flow to a suitable and stable outlet.

6. **Gabions** - similar to stone check dams however the stones in this case are placed on rectangular wire mesh, piled-up as blocks and tied together to form a reinforced wall or dam structure.
7. **Riprap** - concrete structure made of stones constructed along steep embankments to prevent landslide or gully erosion
8. **Stone wall** - made of stones carefully and properly piled-up and arranged on steep embankments to protect from gully erosion or landslide

Gully erosion and control

Gully erosion usually starts as small rills and gradually develops into deeper crevices. The rate of gully formation depends on the amount of runoff, slope and the soil characteristics.

Control measures:

- Grassed waterways - is constructed across the slope above the gully. The grassed waterway intercepts the runoff coming from above the gully.
- Vegetation - can stabilize the slopes of the gully and hence reduce runoff velocities.
- Chute spillways, drops, and drop spillways are permanent structures that can reduce the energy of the runoff water.

Terracing

Functions:

- Reduce sheet and rill erosion
- Prevent gully formation
- Moisture conservation

Types of Terraces

1. **Bench** - construction of series of platforms along the contours cut into the hill slope in a step like formation
 - used for 25-30% slopes
 - used for maximum moisture conservation
 - used where land is at a premium
 - conventional
 - difficult to farm
2. **Zingg or Conservation bench terrace**
 - used for 9-24% slope
 - easier to farm than conventional
 - used for maximum soil and water conservation
3. **Broad-based**
 - a. *Graded or channel type*
 - primary purpose is to remove excess water in such a way as to minimize erosion
 - reduce slope length, conducts intercepted runoff water to outlet at non-erosive velocity
 - outlet either surface or subsurface type
 - b. *Level or ridge type*
 - no grade in channel

- primary purpose is moisture conservation, erosion control is secondary
- channel is normally closed at both ends to assure maximum detention
- adopted to deep, permeable soils
- more formable than bench types
- used where outlets are a problem

Terrace Design

Vertical Interval, $(VI) = aS + b$
for graded terraces

$(VI) = aS + 0.85b$
for level terraces

Horizontal Interval, $(HI) = (VI \times 100)/S$
 $= a(100) + b(100)/S$

Where: a -- constant for geographic location (value range from 0.3 - 0.8 depending on the intensity of rainfall)
 S - average slope above the terrace in percent
 b - constant for soil erodibility and cover conditions
 $b = 1$ erodible soil and poor cover
 $b = 2$ resistant soil and good cover

Grassed Waterways

Grassed waterways are open channels protected with suitable grasses constructed along the slope and act as outlet for terraces and graded bunds. They are also used to safely convey runoff from contour furrows, diversion channels and serve as emergency spillways in farm ponds.

The velocity of flow through the grassed waterways is dependent upon the ability of the vegetation to resist erosion. For design purposes, an average of 1.5 m/s to 2 m/s is used.

Conservation Structures

Drop structures

Structures constructed along a channel to dissipate safely the energy of water by letting the water fall freely for a certain height.

Chute spillways

Vengineering

A term adapted to measures utilizing both or in combination with the biological and engineering measures.

D. Open Channel Flow

Types of Flow

1. **Steady Flow** - discharge is constant with respect to time
2. **Unsteady Flow** - discharge is not constant with respect to time
3. **Uniform Flow** - depth of flow is the same at every section of the prismatic channel
4. **Varied Flow** - depth changes along the length of channel
5. **Rapidly Varied Flow** - if the depth changes abruptly over a comparatively short distance such as in a hydraulic jump
6. **Gradually Varied Flow** - if the depth changes smoothly over a distance
7. **Critical Flow** -- $Fr = 1$
8. **Supercritical Flow** -- $Fr > 1$
9. **Subcritical Flow** -- $Fr < 1$
10. **Laminar Flow** - fluid moves in parallel layers with no cross-currents; $Re \leq 2000$
11. **Turbulent Flow** - characterized by pulsatory cross-current velocities; $Re \geq 4000$
12. **Spatially Variable Flow** - special case of flow in which the discharge varies with distance along the channel

Flow Measuring Devices/Structures

1. Weirs (Rectangular, V-notch, Sharp/Broad -Crested, Proportional, etc.)
2. Parshall Flume
3. Orifice
4. Trajectory

Definition of Terms:

Hydrology - is a science that treats of the waters of the Earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things.

River Stage - is the elevation above some arbitrary zero datum of the water surface at a station along a river or stream.

Staff Gage - a scale set at the river/stream so that a portion of it is immersed in the water at all times to measure river stage.

Soil Erosion - is the detachment and transport of soil particles from the land by water or wind action.

Erosivity - potential ability of the rain to cause erosion. It is a function of the physical characteristics of the rainfall.

Erodibility - vulnerability or susceptibility of the soil to erosion. It is a function of both the physical properties of the soil and land management practices.

Splash / Raindrop Erosion - is soil detachment and transport resulting from the impact of water drops directly on soil particles or on thin water surfaces.

Interrill Erosion - combination of sheet and splash erosion

Rill Erosion - detachment and transport of soil by concentrated flow of water creating shallow rills or furrows.

Gully Erosion - detachment and transport of soil particles by concentrated flow of water creating channels larger and deeper than rills. As differentiated with rill, channels or gullies created cannot be obliterated by normal tillage operation. Thus gully erosion is an advanced stage of rill erosion.

Stream Channel Erosion - consists of soil removal from stream banks or soil movement in the channel.

Drainage coefficient - the depth of water in inches to be removed in a 24 hours period from the drainage area.

$$D_c = i_{pd} = \text{in/day}$$

Infiltration - the passage of water into the soil surface, and the rate is generally expressed in in/hr or cm/hr.

Stilling Basin - structured device designed to hold a pool of water to cushion the impact and retard the flow of falling water as from an overflow weir, chute or drop.

Strip Cropping - consist of growing alternate strip of clean cultivated and close-growing crops in the same field oriented across the slope.

Multiple Cropping or Mixed Cropping - planting different crops simultaneously in the same field at the same cropping season.

Relay Cropping - (crop rotation) planting different crops, one after the other each season.

Flume - are specially shaped and stabilized channel sections which may also be used to measure flow and are generally less inclined than weirs to prevent floating debris and sediments from detention

Culvert - closed conduit usually circular, square or rectangular in cross section, used for conveying water across and under an elevated roadway, embankments, or dike.

Run-off Coefficient - the ratio of depth of run-off to depth of precipitation producing the run-off over a drainage area.

Spillway - a structure for passing out water not needed for storage or diversion.

Water Way - any open or close ground or surface for the passage of water.

Watershed - a topographically delineated area which drains into a reference point in the stream.

Percolation - downward movement of water within the soil.

Seepage - the lateral flow of liquid through porous media; the lost of water from irrigation canals.

Soil Texture - the relative proportion of the various size groups of individual soil grain.

Soil - a natural body composed of mineral and organic material on the surface of the earth on which plants grow.

Drop Structures - a structure which conveys water from a higher to a lower level, maybe inclined or vertical.

Contour Line - an imaginary line of constant elevation on the surface of the ground.

Soil Conservation - the application of engineering principles to the solution of soil management problems, any method used to fully utilize and conserve soil.

Graded Terrace - constructed by cutting a shallow channel on the uphill-side and using only this soil to build the embankment.

Vertical Interval - vertical interval between corresponding points on successive terraces or from top of slope to the bottom of first terrace.

Horizontal Interval - horizontal interval between corresponding points on successive terraces

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